Solar Based Asset Security System

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***Abstract*- The purpose of this project is to develop a renewable solution device i.e. solar-powered asset protection system that is capable of safeguarding precious assets from stray animals and theft in off-grid or remote locations. The system is based on STM32G070KBT6 microcontroller that has a movement detection through PIR sensor, vibration sensor, and light sensor for multi-level intruder sensing. Upon vibration or motion detection, the system activates a DFPlayer Mini module to sound an audio alarm from a speaker while also activating a light for visual discouragement. The greatest advantage of the system is including a Real-Time Clock (RTC) with memory, which records the specific date and time of every intrusion incident. This time-stamped information, movement and vibration detection are shown on a real-term display, with useful event history and facilitating future forensic or monitoring use. The whole setup is powered by a monocrystalline solar panel to charge a 12V battery using a charge controller, and a voltage regulator circuit to deliver a constant 3.3V for the microcontroller. The software part is implemented through STM32CubeIDE where UART and GPIO are used for integrating sensors and audio management. The system provides an energy-efficient, sustainable solution appropriate for remote security use.**

Keywords*- *Event Logging, Intrusion Detection, Remote Asset Protection, Embedded Systems, Renewable Energy, Autonomous Monitoring System, Off-Grid Security Solution.

I. INTRODUCTION

In rural, farm, and industrial site, safeguarding valuable assets from stray animals and unauthorized human intrusion is a priority concern, especially where off-grid electricity supply is not feasible or limited. Traditional security systems are energized and connected on wired frames and therefore inappropriate for such sites. Rather, the present project proposes a Solar-Based Asset Security System—a standalone, power-independent asset protection measure for off-grid or remote locations. The STM32G070KBT6 microcontroller, the heart of the system, was selected based on low power consumption and strong peripheral support. The system makes use of a combination of three sensors to facilitate multi-layered sensing: a PIR (Passive Infrared) sensor to recognize human or animal motion, a vibration sensor to recognize physical shock or tampering, and a light sensor to sense levels of ambient light, which can be used for varying system response based on day/night cycle. Upon detection of motion or vibration, the system triggers a DFPlayer Mini sound module to play audio recording of warning sound through a speaker, as well as lighting a light source for threat deterrence. The additional functionality of this system is the memory-based Real-Time Clock (RTC) that captures the date and time for each detection incident. This data is displayed in real-time, with a record of intrusions to assist with accountability and monitoring capability. The power is supplied by a monocrystalline solar panel, charging a 12V battery assisted by a solar charge controller to power continuously even when grid power is down. Voltage regulator circuit is used to regulate voltage from the battery to 3.3V to use in the STM32 microcontroller. STM32CubeIDE is built upon, upon which GPIO, UART, and RTC libraries are used for sensing using proper interfacing of the sensors, data storage, and control output. With the integration of renewable power, intelligent sensing, and time-stamp event logging, this project presents a practical and real-world usable solution to asset protection.

II. LITERATURE SURVEY

It offers a remote solar-powered monitoring system general-purpose design framework based on photovoltaic panel configuration analysis, energy storage components, and system reliability. The key research areas include smart power management, weather endurance, and always-on functionality.[1]

Compares and contrasts between different motion sensor technologies like PIR, ultrasonic, and microwave sensors on the grounds of accuracy, range of detection, response time, and power requirement. Provides sensor selection guidelines to facilitate maximum power-saving sensor selection for solar- or battery-powered security systems.[2]

Trains on maximum practice battery management techniques to attain maximum efficiency and life for solar equipment. Trains on the types of battery, charge-discharge cycles, thermal reliability, and monitoring procedures utilized to obtain maximum reliability and optimize working life in off-grid applications.[3]

Seeks to use a low-power security system that beeps and flashes lights to warn. Seeks to save energy using smart triggering devices, yet still retain the capability to provide proper visual and audible warnings to deter trespassers or wildlife.[4]

Explains implications of environmental factors like UV radiation, humidity, dust, and temperature fluctuation on operation of solar-powered IoT system. Suggests covers and materials to render it robust in long-term field deployment. [5]

Provides best example for solar-powered monitoring system deployment for use in wildlife damage prevention and detection in agricultural application. Provides very effective use of clean energy to low-cost low-maintenance installation deployment in susceptible environments. [6]

Discussions of using solar-powered security systems in securing valuable commodities such as oil pipelines, electricity substations, and telephone masts. Possesses system designability, real-time monitoring, minimal cost, and capability to operate with little supervision in remote locations.[7]

Employs power-conserving technology of solar-charging Internet of Things-based security solutions. Employs power-conserving techniques, intelligent battery management, and load optimization in order to operate even during low-light or clouding conditions.[8]

Has a built-in solar-powered IoT device platform for live monitoring of farm equipment. Provides IoT protocol deployment, solar integration, and data transport capabilities to enable responsive, low-maintenance remote security surveillance.[9]

Utilize the NB-IoT and LoRaWAN wireless technologies in an effort to enable off-grid solar-powered security system communication. Particularly keen on employing low power, long range, and interval transmitting in order to ensure a system lasts as long as possible when mounted off-grid or remotely. [10]

III. METHODOLOGY

The system intended is meant to detect illegal movement and vibration around an unidentified asset depending on the application of solar power as the source of power. The process consists of the following major components and their flow of operation as shown in Fig.1: Monocrystalline solar panel is the power source. Power is directed to a charge controller, in which the power is charged and stored in a rechargeable 12V battery. For compatibility of the power to be fed to the microcontroller, the voltage level of 12V is stepped down by a voltage regulator circuit to 5V and further reduced to 3.3V DC, compatible with the STM32G070KBT6 microcontroller.

Central to the system is the STM32G070KBT6 microcontroller, whose responsibility is to communicate with all the sensors, process inputs, execute control logic, and execute outputs. There are three sensors that make up the system:

PaPIR Sensor (Motion Detection): Implements detection of human beings or animals within close proximity around the asset, Vibration Sensor: Implements detection of physical contact or vibration and Light Sensor: Uses ambient light sensing to support decision-making for the use of visual deterrents.

Upon detection of vibration or movement: The DFPlayer Mini Module will output a recorded sound through a connected speaker in an effort to frighten intruders away. LED lights are also illuminated to signal visually or frighten would-be intruders, especially during low-light environments.

The system includes memory and a Real-Time Clock (RTC). In case any movement or vibration is sensed, the date and time of detection are logged and can be retrieved using Rea-Term or other serial monitoring programs of a similar nature. This adds responsibility and allows a log to be kept for future examination. By using all the low-power devices and solar power, the system is designed for remote installation and low maintenance. Efficient power distribution enables it to run continuously even in the event of fluctuations in sunlight.

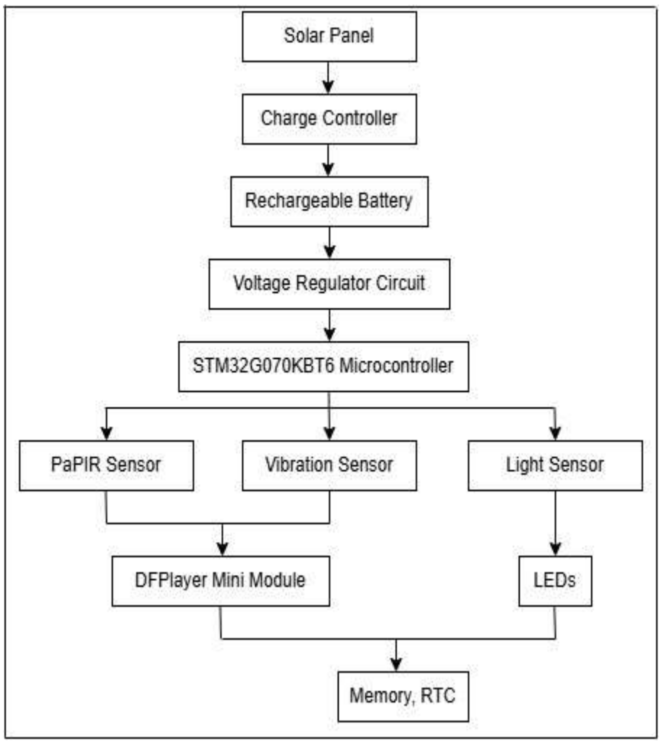

Fig.1 Block Diagram

IV. IMPLEMENTATION

A. *Software Design Description*

The "Solar-Based Asset Security System" was developed with code in STM32CubeIDE, which is an STMicroelectronics integrated development environment. The system is intended to simplify the process of setting up graphical peripherals via a .ioc file and Embedded C programming. STM32G070KBT6 microcontroller is utilized, and the primary purpose of the software is to engage with other sensors (PIR, vibration, and light) and perform corresponding action based on sensor input. Following is the specific details about software implementation:

1. Operating System: The system does not run on its own operating system or Real-Time Operating System (RTOS). Bare-metal embedded programming is utilized, and the STM32G070KBT6 microcontroller runs code directly natively without an OS level. The system maintains a fixed memory footprint.

2. Programming Language: The whole software has been developed in Embedded C, within STM32CubeIDE. The IDE has HAL libraries which make peripheral initialization and management easy. Embedded C has been utilized as it provides support for low-level hardware management, is lightweight, and has good support for STM32 microcontrollers.

3. Software Architecture: The Architecture is polling-based and modular. Every sensor is dealt with by distinct polling logic within the primary loop. Code consists of initialization procedures (UART, GPIO) and always-running execution loop reading sensors, making decisions, and initiating output action (sound, LED, UART print). The linear state-based architecture is straightforward to debug and produces deterministic responses without the latency of interrupts or multithreading.

4. Image Preprocessing Module: This module is not used in this project because it does not handle video or image processing. Signal capture from vibration, motion, and light sensors in real time and not video data is the focus.

5. User Interface Module: There isn't any standard GUI employed in this project. Instead, it employs a serial terminal (SIMComSPT_V3.5) on a PC as a textual interface. Real real-time system messages like "Motion Detected" or "No Motion" are observable to the user through UART communication. The terminal is also a user monitor interface employed by test engineers and developers for monitoring sensor response and system behavior.

6. Main Control Module: The primary control logic resides in the main.c file, which boasts the central function. It initializes the periphery, reads from sensors, software bounces the motion detection to the software level, and sends associated UART messages. In case an actual threat event is sensed (motion or vibration), the control module then turns on the LED and requests the DFPlayer Mini audio module to trigger warning audio through a speaker. It reverts to the original state when user intervention occurs. The central control module is responsible for the synchronized operation and stable performance of the security system.

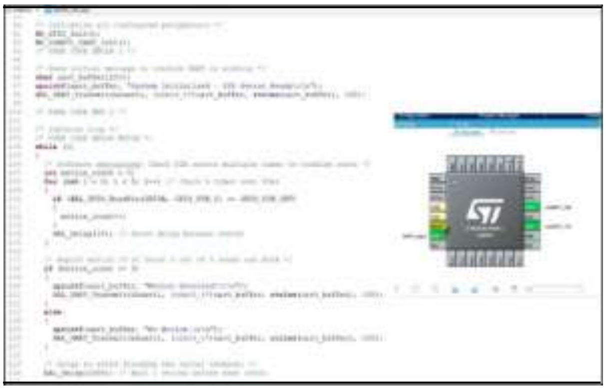

Fig. 2 Software Implementation (Input)

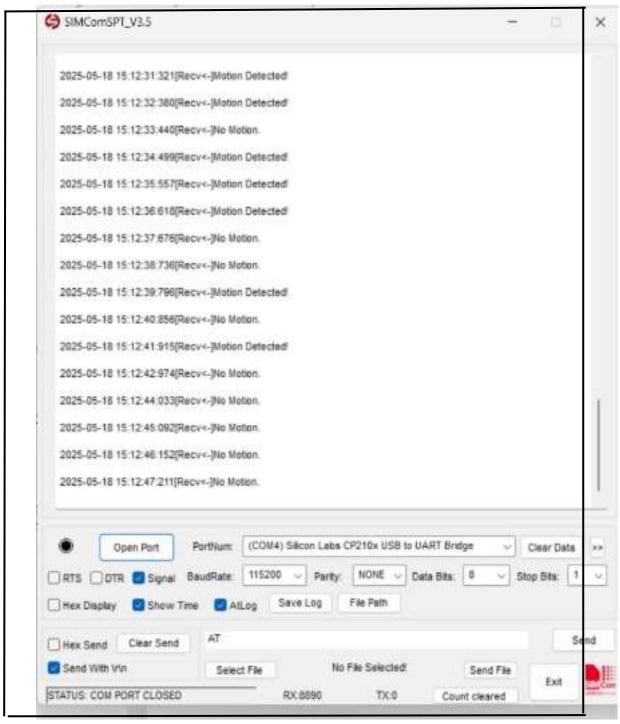

Fig. 3 Software Implementation (Output)

Following is the explaination for Fig 2 & Fig 3:

- The PIR motion sensor is then connected to pin PA0, which being the digital input pin is configured through the GPIO peripheral by STM32CubeMX .ioc configuration tool. USART1 peripheral is also configured to UART, and PA9 is utilized as TX pin and PA10 as RX pin. 115200 bps baud rate is used in the serial communication of microcontroller with PC terminal for observation and monitoring. PC-based SIMComSPT_V3.5 software is used to graphically show and log UART messages.

- The basic motion detection logic is coded in main.c in Embedded C. After GPIO and UART peripherals are initialized, a "System Initialized - PIR Sensor Ready" message is sent via UART to show that the system is coming up properly. The infinite while loop then continuously checks the PIR sensor for motion. To make it more solid and prevent spurious triggering because of sensor noise or glitch, software debouncing is employed. That is done by taking the PIR sensor five samples quickly with 10-millisecond gap in between samples. If three out of five samples are of HIGH state (GPIO_PIN_SET), software determines that motion has detected.

- Whenever movement is detected, the system broadcasts the "Motion Detected!" message via UART. If there is no motion detected, "No Motion." message is sent accordingly. The process is noise-proof and accurate in detection. One-second delay is provided after each cycle of motion detection to avoid UART terminal message overflow. The efficiency of such a setup is verified by real-time UART traces observed in the SIMComSPT software with alternating motion detect messages based on sensor input. This gives the developers and testers a clear picture of how the system will behave in real circumstances.

B. Hardware Design Description

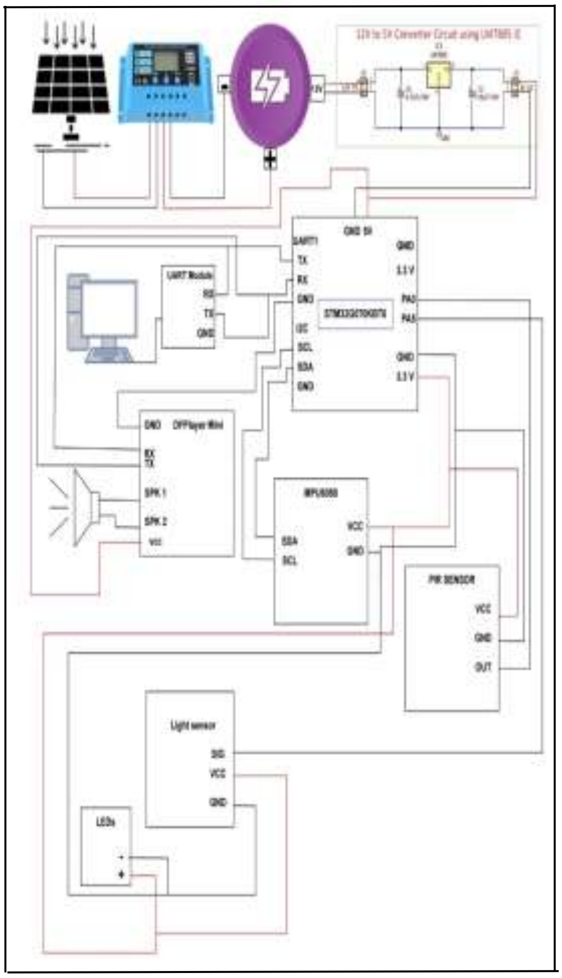

Fig. 4 Circuit Diagram

1. Microcontroller (STM32G070KBT6): The central part of the system is the STM32G070KBT6 microcontroller control unit. It is a 64 MHz 32-bit ARM Cortex-M0+ MCU featuring 128 KB Flash and 36 KB SRAM memory. It interfaces with all the modules and sensors to receive the environmental inputs read and react accordingly. GPIO pins are utilized in input (e.g., PIR sensor) and output (e.g., LED indicators and regulation of DFPlayer Mini) modes.

Fig. 5 STM32G070KBT6 Microcontroller

2. PaPIR Motion Sensor (PIR Sensor): Panasonic PaPIR sensor is employed to detect the movement accurately. It is connected on microcontroller GPIO pin PA0. The sensor detects the changes in the infrared radiation emitted due to movement in its line of sight and provides a digital HIGH output signal when it detects movement.

3. Vibration Sensor (MPU6050): The pins connection of vibration sensor are I2C1_SCL to PB6 and I2C1_SDA to PB9. It is sensitive to physical motion such as shaking, tapping, or an object to be guarded being disturbed. The secondary protection is offered by the sensor because it is sensitive to vibrations which might not be able to detect the PIR sensor.

4. Light Sensor: The light sensor is connected through ADC1_IN0 to PA5. It's an ambient light sensor and used for on/off switch control of indicator LEDs. Used for environmental monitoring if vibration or movement is detected.

5. LED Indicators: LEDs are used as a visual alerting system on detection of motion or vibration. They are powered through GPIO pins defined as output and switched based on sensor inputs.

6. The DFPlayer Mini MP3 Audio Module: This module is used for audio playback and is interfaced to the STM32 using UART1 (PA9 - TX and PA10 - RX). The module outputs a recorded sound through an interfaced speaker to frighten away intruders (animals or thieves) whenever intrusion or vibration is detected.

7. Speaker: Interfaced to the SPK1 and SPK2 pins of the DFPlayer Mini, this speaker sends an audible signal to nearby humans or animals upon sensing intrusion.

8. Power Supply:
   - The power source utilized to energize the system is a 12V rechargeable battery.
   - Voltage regulators provide the 5V and 3.3V utilized by the microcontroller and sensors.
   - Power to the system comes from a solar panel via a solar charge controller. This provides stable, reliable power for outdoor 24/7 use.

Fig. 6 Solar Panel with Charge Controller & Battery

9. UART Communication for Debugging: A UART-USB bridge (PA9 for Tx and PA10 for Rx) is connected to the STM32 UART1 port to transfer data to the SIMComSPT terminal of a PC. It is utilized for real-time monitoring of sensor status like "Motion Detected" or "No Motion".

10. Hardware Implementation:

Fig. 7 Final Combine Implementation

IV. RESULT

The Solar-Based Asset Security System operated effectively to safeguard an unnamed asset through the combination of renewable energy with automatic detection and deterrent systems. The PaPIR motion sensor and vibration sensor detected movement and physical disturbances on a continuous basis, triggering the DFPlayer Mini to emit a sound alarm and activating LEDs as a visual signal. These parts worked together to repel both human intruders and wild animals. The light sensor saved power by allowing lighting only during low-light conditions. The detection events were timestamped precisely using the onboard Real-Time Clock (RTC), and the logged data was shown on Real-Term via UART, allowing real-time observation. The system was powered solely by a monocrystalline solar panel to a charge controller, rechargeable battery, and voltage regulators that provided a constant 3.3V DC to the STM32G070KBT6 microcontroller.

V. CONCLUSION AND FUTURE WORK

The Solar-Based Asset Security System achieved addresses the demand for a free-standing, power-saving security product for off-grid or rural situations. With incorporation of solar, motion, vibration, and light sensing, the system delivers effective intrusion detection, along with smart deterrence using audio and optical signals. Installation of a Real-Time Clock as well as provision of data logging adds more serious monitoring and verification.
Its deployment with renewable energy and low-power equipment guarantees its sustainability for long-term deployment without maintenance and independence from the grid. This project illustrates the potential of integrating embedded systems, clean energy, and real-time monitoring for smart, green asset protection solutions.

The Solar-Based Asset Security System also has a promising future of development and actual application. Future advancements will further develop its intelligence, network connectivity, flexibility, and energy efficiency. It can include a Wi-Fi module to receive real-time cloud notifications and remotely access, aside from having LoRaWAN or NB-IoT capabilities for farther connectivity distance. Other added features are inclusion of a camera module, intrusion classification using AI, web/mobile interfaces, GPS tracking, MPPT charging, tamper detection, and expandable sensor modules that make the system wiser, scalable, and versatile.

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